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Influence of Er and O doses in Er-related emission in $Al_{0.70}Ga_{0.30}As$:Er

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ABSTRACT

Er ions with doses ranging from $1x10^{13}$ cm^{-2} to $1x10^{15}$ cm^{-2} were implanted into $Al_{0.70}Ga_{0.30}As$ on GaAs substrates. at 800 ^{o}C. Photoluminescence (PL) intensity of Er-related emission around 1.54 μm was enhanced by co-implanted oxygen (O). The optimum dose of Er ion was $1x10^{14}$ cm^{-2} and O ion was $1x10^{15}$ cm^{-2}, respectively. Furthermore, from the temperature dependence of the PL intensity of sample implanted with the optimum dose, we estimated the values of E_1, E_2, and E_3, the activation energies in order to investigate the rapid thermal quenching of Er ion in $Al_{0.70}Ga_{0.30}As$. We found that PL intensity of Er-related emission, in addition to O dose, was enhanced approximately twenty two times at room temperature. And from the temperature dependence of the lifetime of the optimum dose of Er and O, the value 245meV of E_A, the activation energy for the decrease of the lifetime, was nearly equal to the value 235meV of E_3. Based on the result, the decrease of the lifetime confirms that the radiative efficiency is lower; therefore, we propose that rapid thermal quenching occurs at temperatures above 200 K due to the decrease of the radiative efficiency.

INTRODUCTION

Rare-earth(RE) impurities in III-V semiconductors have attracted much attention due to their potential applications in new emitting devices and based on the internal emission from the 4*f* levels of the impurity. The intra-4*f* shell transitions cause sharp and temperature-stable luminescence because of shielding by outer electronic shells. [1,2] Therefore the research on the optical devices, which involves RE element, has been advanced. Er is attractive for obtaining light emitting device in silica-fiber-based optical communication systems. As a matter of fact, the luminescence from Er^{3+} ion occurs at a wavelength of 1.54 μm [3,4], which corresponds to the minimum absorption of silica-based optical fibers.

However Er-doped semiconductors have problems such as low energy transition efficiency from the host semiconductor to the intra-4f-shell of Er^{3+} ions. Therefore it is important that we understand the mechanism of the energy transition. We have previously reported photoluminescence (PL) properties for the dependence of the composition ratio (x) in $Al_xGa_{1-x}As$, and the influence of light elements (O, N, and C) on the low dosage $1x10^{13}cm^{-2}$ of Er. [4]

In this work, we studied the influence of O on Er^{3+}-related emission with the high Er doses ranging from $1x10^{14}cm^{-2}$ to $1x10^{15}cm^{-2}$.

EXPERIMENT

Er^{3+} ion of 1 MeV were implanted into undoped $Al_{0.70}Ga_{0.30}As$ (100) grown by molecular beam epitaxy (MBE) with doses ranging from $1x10^{13}$ cm^{-2} to $1x10^{15}cm^{-2}$ at room temperature. The projected range (R_p) and straggling (ΔR_p) for implant profile were calculated by materials computer program (TRIM) to be 205.7 and 58.4nm, respectively. O ion were implanted into $Al_{0.70}Ga_{0.30}As$:Er with doses ranging from $1x10^{13}$ cm^{-2} to $3x10^{15}cm^{-2}$ at an energy of 130 keV. The R_p of the implanted O ions was almost the same as that of Er ions. After implantation, these samples were isochronally annealed for 10 min. at 800 °C, using the proximity cap method in H_2 atmosphere. In order to characterize the specimens, PL measurements were carried out using a 1m focal length double monochromator and photo-multiplier (Hamamatsu Photonics R5509-72). Samples were excited by the 488.0 nm line of an Ar ion laser with a power of 10 mW.

RESULTS AND DISCUSSION

In order to optimize the PL intensity of Er^{3+}, dose dependence was investigated. Figure 1 shows the Er-related PL spectra of $Al_{0.70}Ga_{0.30}As$:Er for doses ranging from $1x10^{13}$ cm^{-2} to $3x10^{15}cm^{-2}$ measured at 15K. The several peaks were observed around 1500nm, and the dominant peak is located 1539.6 nm. PL intensity of the dominant peak increased for Er doses ranging from $1x10^{13}$ to $1x10^{14}$ cm^{-2} and decreased for those from $3x10^{14}$ to $1x10^{15}$ cm^{-2}. In the sample with Er dose of $1x10^{14}$ cm^{-2}, the PL intensity of the dominant peak

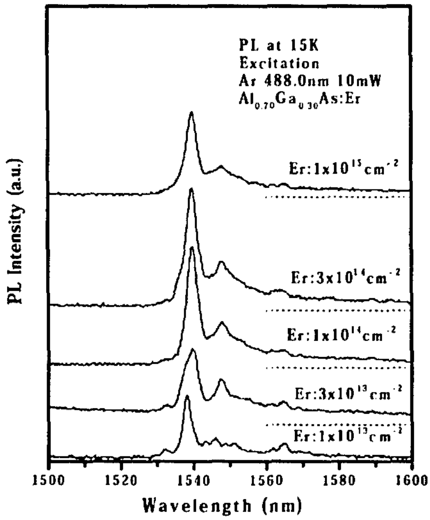

Figure 1. PL spectra of Er^{3+} ion in $Al_{0.70}Ga_{0.30}As$ corresponding to the transition $^4I_{13/2} \longrightarrow {}^4I_{15/2}$ recorded at 15K with Er doses ranging from $1x10^{13}$ cm^{-2} to $1x10^{15}cm^{-2}$.

at 1539.6nm was maximum. The dominant peak intensity decreased with increasing the Er doses range above $1x10^{14}$ cm^{-2}.

Figure 2. shows the PL spectra of $Al_{0.70}Ga_{0.30}As$:Er,O for different O doses and annealed at 800℃ measured at 15K. As the O dose increased from $1x10^{14}cm^{-2}$ to $1x10^{15}$ cm^{-2}, the dominant peak was stronger. In the sample, when O was co-implanted into the $Al_{0.70}Ga_{0.30}As$:Er with a dose of $1x10^{15}$ cm^{-2}, the PL intensity of the dominant peak became maximum. The peak intensity decreased with increasing the O doses from $1x10^{15}$ cm^{-2} to $3x10^{15}$ cm^{-2}. We consider that the PL intensity in the sample with the O dose at $3x10^{15}$ cm^{-2} decreases because the defects attributed to O co-doping disturb the energy transition efficiency from the host material to the intra-4f-shell of Er^{3+} ions. Based on the results, the O dose required to obtain the maximum PL intensity at the dominant peak is concluded to be $1x10^{15}$ cm^{-2}.

Figure 3 shows the temperature dependence of PL intensity for $Al_{0.70}Ga_{0.30}As$:Er, O at Er dose of $1x10^{14}cm^{-2}$ and O dose of $1x10^{15}cm^{-2}$. From Figure.3, we can observe a peculiar three -step quenching process in PL intensity of Er:$1x10^{14}cm^{-2}$ without O and Er:$1x10^{14}$, O:$1x10^{15}cm^{-2}$. The PL intensity rapidly decreased above 200K. Furthermore, at room temperature the PL intensity of Er-related emission from the sample co-implanted with O at a dose of $1x10^{15}cm^{-2}$ was twenty two times stronger than that from the sample implanted with

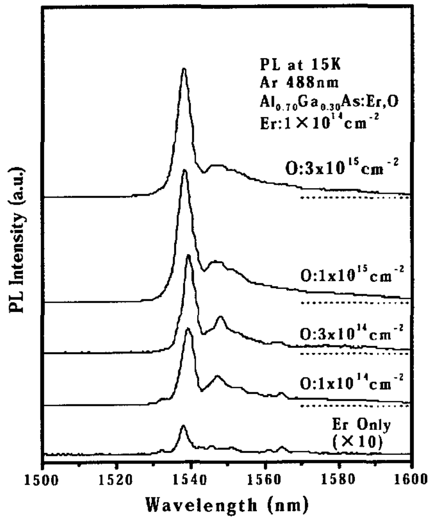

Figure 2. PL spectra measured at 15K for $Al_{0.70}Ga_{0.30}As$:Er,O with O doses ranging from $1x10^{15}$ cm^{-2} to $3x10^{15}$ cm^{-2}.

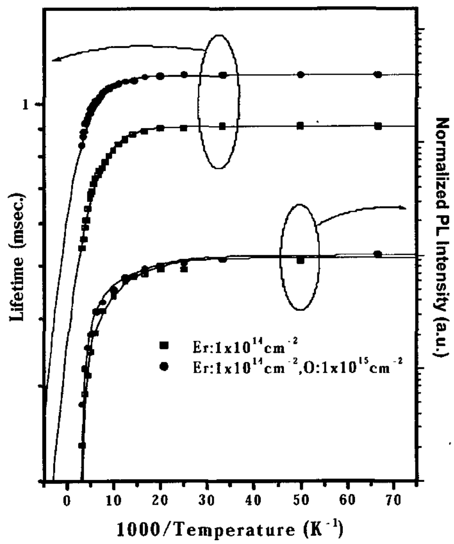

Figure 3. Er^{3+}-related PL lifetime and intensity dependence on temperature for $Al_{0.70}Ga_{0.30}As$:Er,O.

only Er:1x10^{14}cm^{-2}.The experimental data for $Al_{0.70}Ga_{0.30}As$:Er,O are plotted together with the theoretical lines (solid line) of the best fit obtained using Eq. (1) using parameters (C_1,C_2,C_3,E_1,E_2,E_3) shown in table 1.[6-8]

$$I = I_0/\{1 + C_1 \exp(-E_1/kT) + C_2 \exp(-E_2/kT) + C_3 \exp(-E_3/kT)\} \tag{1}$$

$$1/\tau(T) = 1/\tau_r + 1/\tau_n \tag{2}$$

Where τ_n (the non-radiative lifetime) was assumed as follows:

$$1/\tau_n = C_A \exp(-E_A/kT) \tag{3}$$

Table 1. Activation energies obtained by fitting experimental results to Eqs. (1) and (2).

PL Intensity

	C_1	E_1(meV)	C_2	E_2(meV)	C_3	E_3(meV)
Er:1x10^{14}cm^{-2}	5.0	14.0	50	50	4.0x10^5	235
Er:1x10^{14}cm^{-2} O:1x10^{15}cm^{-2}	3.0	11.5	55	60	2.0x10^5	235

Lifetime

	C_A	E_A(meV)
Er:1x10^{14}cm^{-2}	1.7	235
Er:1x10^{14}cm^{-2} O:1x10^{15}cm^{-2}	0.75	245

In the above equation, I_0 is the intensity when the electron emission from the Er-related trap can be neglected. Hence it corresponds to the intensity at a very low temperature. T is the measuring temperature, E_1, E_2, E_3 and E_A, are activation energies respectively, and k is the Boltzmann constant. C_1, C_2, C_3 and C_A are the coupling coefficient at E_1, E_2, E_3 and E_A, respectively. τ and τ_r are the lifetime and the radiative lifetime, respectively. These E_2, and E_3 values were 50-60 meV and 235 meV, respectively. Moreover, E_A values were 235-245 meV. On the other hand, the value 235meV of E_3, the activation energy for rapid thermal quenching, was nearly equal to the value 235-245meV of E_A, activation energy for the decrease of the lifetime. Based Eq. (2), the decrease of the lifetime confirms that the radiative efficiency is lower; therefore, we propose that rapid thermal quenching occurs above 200 K due to the decrease of the radiative efficiency. In addition, we infer that activation energy E_1 is the ionization energies of the e-h pair in the Er^{3+}-related trap level because it has been reported that the ionization energy is about 10 meV.[4,7]

CONCLUSION

In order to increase Er-related emission in $Al_{0.70}Ga_{0.30}As$, we examined dose dependence of Er and O. It was found that the optimum dose range for $Al_{0.70}Ga_{0.30}As$:Er was $1x10^{14}$ cm^{-2}, based on the dose dependence, and the optimum O dose range for $Al_{0.70}Ga_{0.30}As$:Er was $1x10^{14}$ cm^{-2},based on the O dose dependence. The PL intensity of Er-related emission, in addition to O dose, was enhanced approximately twenty two times at room temperature. From the temperature dependence of the PL intensity and the lifetime, E_3 (235meV), the activation energy for rapid thermal quenching, was nearly equal to E_A (235-245meV) the activation energy for the decrease of the lifetime. Based on the result, the decrease of the lifetime confirms that the radiative efficiency is lower; therefore, we propose that rapid thermal quenching occurs above 200 K due to the decrease of the radiative efficiency.

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